PN-ABY-374

98934

ENVIRONMENTAL HEALTH PROJECT

ACTIVITY REPORT

No. 17

An Evaluation of Technical Options for Improvement of the Wastewater Treatment System at the RAS Kiviter Oil Shale Chemical Plant Kohtla-Järve, Estonia

Frank J. Castaldi, Ph.D., P.E.

March 1996

Prepared for RAS Kiviter, Kohtla-Järve, Estonia
under EHP Activity No. 228-RC

Environmental Health Project
Contract No. HRN-5994-Q-00-3037-00, Project No. 936-5994
is sponsored by the Bureau for Global Programs, Field Support and Research
Office of Health and Nutrition
U.S. Agency for International Development
Washington, DC 20523

CONTENTS

TABLES

ABOUT THE AUTHOR

Frank J. Castaldi, Ph.D., P.E. is a Principal Engineer and resident expert for wastewater and solid hazardous waste process engineering design in the Austin office of Radian International LLC. Dr. Castaldi holds eight U.S. and international patents for wastewater and hazardous waste treatment inventions. His responsibilities at Radian International include technical direction and project management in water and wastewater treatment projects, research and development studies in solid and aqueous hazardous waste treatment, and engineering consultation to U.S. and foreign industries on waste treatment practice. His areas of expertise include biological treatment of industrial wastewater and solid hazardous wastes, treatment process development, waste management, and process engineering design.

EXECUTIVE SUMMARY

This report presents the results of an evaluation of technical options for improvement of the regional wastewater treatment system at the Kiviter Oil Shale Chemicals facility in Kohtla-Järve, Estonia. The work is funded by the United States Agency for International Development (USAID) and is carried out by the Environmental Health Project (EHP). The overall goals of the work are to reduce environmental pollution and the resulting threats to human health and to improve the financial viability of Kiviter.

The study assessed the performance of the existing wastewater treatment system and the impact future municipal and industrial waste loadings will have on the facility's capacity to achieve compliance with the "Helcom Recommendations," the requirements of the Helsinki Commission on treated effluent discharging to the Gulf of Finland. The study also examined pretreatment of spent shale pile runoff water and other wastewater sources. The evaluation of technical options for improvement of the wastewater treatment system concluded that the existing facility does not meet treated effluent discharge requirements because of a combination of process configuration and equipment-related deficiencies which have prevented the wastewater treatment plant from achieving treatment levels consistent with available capacity. Biological treatment alone will not be capable of meeting the future "Helcom Recommendations" for total nitrogen. Therefore, it is recommended that source treatment and/or control of nitrogen levels in the various industrial wastewaters entering the regional wastewater treatment plant be implemented.

The study concluded that the high-strength, low-volume wastewater from the new benzoate esters production facility will require effective equalization and neutralization prior to discharge to the regional wastewater treatment plant. This will allow adequate opportunity for effective dilution of this wastewater after commingling with the other industrial and municipal waste sources at Kohtla-Järve, thus reducing the impact of this waste source and making the benzoate esters wastewater more amenable to effective biodegradation in the activated sludge process at the regional treatment works.

The diversion of spent shale pile runoff to engineered waste stabilization ponds is considered an effective pretreatment of these wastewaters prior to commingling with other industrial waste streams at the regional wastewater treatment facility at Kohtla-Järve. Improvement of the wastewater treatment facility will require upgrade of existing preliminary and primary treatment systems; modification of the existing activated sludge treatment process to a complete-mix process configuration; conversion to single-stage activated sludge treatment; modification of the existing return activated sludge conveyance system; and upgrade of the existing second-stage (final) activated sludge sedimentation tanks.

The study also concludes that it is more cost-effective to continue repairs and retrofits of the existing fine-bubble, porous diffuser aeration system than to replace the entire aeration system with new diffusers or alternate aeration devices. Adequate air compressor capacity exists at the Kohtla-Järve wastewater treatment facility to produce air for future activated sludge mixing and aeration requirements. Granular media filtration of activated sludge process final sedimentation effluent will be necessary to meet the "Helcom Recommendations" for effluent suspended solids. This approach is more cost-effective than the expansion of the final sedimentation tank capacity (i.e., post-sedimentation basins) recommended by Oy Vesi-Hydro AB.

1 BACKGROUND

The evaluation of technical options for improvement of the regional wastewater treatment system at Kohtla-Järve is one of seven technical tasks under Phase II of work at the Kiviter Oil Shale Chemicals facility in Kohtla-Järve, Estonia. The work is funded by the United States Agency for International Development (USAID) and is carried out by the Environmental Health Project (EHP). The overall goals of the work are to reduce environmental pollution and the resulting threats to human health and to improve the financial viability of Kiviter.

The existing wastewater treatment plant (WWTP) at the Kiviter facility is a two-stage biological treatment system. It treats industrial wastewater and sewage not only from Kiviter but also from other nearby industries and municipalities. The existing wastewater treatment plant presently treats between 28,000 and 36,000 m^3/d of industrial and municipal wastewaters. The addition of several new industrial and municipal wastewater sources will increase the volume of wastewater for treatment to 55,000 m^3/d. At issue is the regional WWTP's ability in the future to meet the treated effluent requirements of the Helsinki Commission for the Baltic Sea presented in the "Helcom Recommendations." These recommendations state that a wastewater treatment plant discharging to the Gulf of Finland must produce a treated effluent with the following quality:

- BOD_7 ≤15 mg/L
- Suspended Solids ≤15 mg/L
- Total Phosphorus ≤ 1.5 mg/L
- Volatile Phenols ≤ 0.5 mg/L

Additionally, a long-term goal of the "Helcom Recommendations" is to reduce the total nitrogen load to the Gulf from any given discharge by 75 %.

The primary purpose of this task was to review the technical feasibility of options to improve the performance of the Kohtla-Järve regional wastewater treatment system. It is beyond the scope of this task to determine the institutional or financial viability of the options.

The wastewater treatment options evaluation provided the following:

- Information to increase the understanding of Kiviter personnel of the practicable treatment options and their attractiveness to Kiviter.
- An assessment of the existing Kohtla-Järve wastewater treatment system.
- An assessment of future regional wastewater treatment waste loadings and their impact on the effectiveness of the existing and future WWTP at Kohtla-Järve.
- An examination of spent shale pile runoff water pretreatment and its impact on the design of the future WWTP at Kohtla-Järve.
- An examination of options for improvement of the Kohtla-Järve regional WWTP to meet future waste loadings and achieve compliance with the "Helcom Recommendations."
- Recommendations for improvement to the Kohtla-Järve regional WWTP which may be implemented using existing treatment equipment and appurtenances.

2 EVALUATION OF EXISTING WASTEWATER TREATMENT SYSTEM

The existing Kohtla-Järve wastewater treatment plant treats a combination of municipal and industrial wastewaters using a two-stage activated sludge process. The municipal wastewaters are pretreated in a section of the WWTP which provides comminuting devices, vortex grit removal systems, and primary solids sedimentation. The industrial wastewaters, which include waste streams from the Kiviter dephenolization plant, Kiviter tar recovery plant, RA Eesti Kiviõli shale oil operations, Nitrofert production operations, and Püssi particle board manufacturing, are combined with the pretreated municipal wastewaters before entering aerated equalization basins in the main body of the WWTP. (The municipal wastewaters also include a portion of industrial wastewaters from those production factories that are connected to the municipal sewerage system—e.g., RAS Püssi-PPK.) Once the various wastewater sources are blended in the Kohtla-Järve facility equalization basins, the combined wastewater is directed to activated sludge treatment for removal of soluble and insoluble organic constituents found in the individual waste streams. Treated effluents from the second-stage activated sludge sedimentation tanks are discharged via a pipeline and deep-water outlet to the Gulf of Finland. Waste sludge dewatering and digestion is not performed at the wastewater treatment facility. The waste sludge is pumped to a nearby waste disposal area directly from the sedimentation tanks.

The treatment performance of the existing Kohtla-Järve biological treatment process is summarized by the data presented in Table 1. The information presented includes influent and effluent data for 7- and 21-day biochemical oxygen demand (BOD), chemical oxygen demand (COD), total and volatile phenols, and suspended solids, among other constituents. These data suggest that the treatment performance of the Kohtla-Järve activated sludge process is, in part, adversely impacted by the high solids carry-over associated with the operation of the second-stage activated sludge sedimentation tanks. The data indicate that removals of BOD_7 and COD from the combined municipal and industrial wastewaters were 81% and 49%, respectively, with effluent suspended solids present in the sample, but improved to 91% for BOD_7 and 70% for COD when the suspended particulate was removed from the treated effluent. Similar results were also apparent for measured BOD_{21} and phosphorus in the combined municipal and industrial wastewaters. It is conceivable that if the effluent suspended solids were reduced to concentration levels consistent with the requirements of the Helsinki Commission for the Baltic Sea presented in the "Helcom Recommendations" (i.e., 15 mg/L TSS), the existing WWTP could possibly also meet the stipulated effluent requirements for BOD_7, total phosphorus, and volatile phenols (i.e., 15 mg/L BOD_7; 1.5 mg/L total phosphorus; and 0.5 mg/L volatile phenols). However, this premise must be examined in light of the additional waste pollutant and hydraulic loads that will be associated with the future regional wastewater treatment facility at Kohtla-Järve. For example, the existing biological WWTP is not effective at nitrification of influent ammonia. The data presented in Table 1 indicate that the majority of the nitrogen removed by the process is associated with microorganism maintenance (i.e., biomass synthesis), and less than 32% of the remaining ammonium-nitrogen undergoes conversion to nitrites and nitrates. There also may be possible inhibitory effects on biological nitrification associated with the presence of phenolics in the Kiviter and Kiviõli wastewaters, as evidenced by the presence of high residual nitrite concentrations in the treated effluents. The literature indicates that phenol present in the activated sludge process mixed liquor above 5.0 mg/L will inhibit ammonia oxidation by bacteria (Richardson, 1985).

The influence of treatment stage on the performance of the existing biological treatment process is examined with the presentation of the data assembled in Table 2. These data indicate that approximately 24% of the total BOD_7 and 60% of the settled BOD_7 is removed across the first-stage of the Kohtla-Järve activated sludge process. Removals of volatile and total phenols averaged approximately 71% and 52%, respectively, in the first-stage of the biological process. It is apparent that suspended particulates in the effluents of the first-stage activated sludge sedimentation tanks also impacted the treatment performance of this process. However, it is also true that this condition results from a low active biomass under aeration and a relatively short hydraulic residence time in the first-stage biological process, all other parameters not withstanding. (System mean cell residence times [i.e., sludge ages] were not calculable with the data provided.) The overall treatment performance of the Kohtla-Järve activated sludge process also was adversely impacted by the damaged condition of the fine-bubble porous diffuser system in several of the biological reactors (i.e., aeration basins). These porous diffuser systems were undergoing repair at the time of this evaluation. Nevertheless, despite the damaged condition of the porous diffuser system, the Kohtla-Järve wastewater treatment process is still performing reasonably well for carbonaceous BOD_7 and phenolics removal when the excess suspended particulate load is accounted for in the analysis of these constituents. Table 2 also presents data for the relative magnitude of several of the more conventional process design parameters associated with the activated sludge process. These data indicate that such parameters as the food-to-microorganism ratio (i.e., sludge loading), sludge volume index (SVI), sedimentation tank hydraulic loadings, and the apparent sedimentation tank solids loadings are all within acceptable levels for normal activated sludge treatment system operation. Moreover, the apparent level of aeration (17.7 $m^3/min/m^3$) provided to the biological process greatly exceeds the oxygen utilization requirements needed for effective treatment of the biochemical oxygen demand in the influent wastewater. Albeit, this level of aeration will be necessary for the mixing of activated sludge solids in the process.

The existing aeration basins consist of four reaction compartments, or bays, which are arranged for plug or series flow of wastewater and return activated sludge. Traditionally, a plug flow tank geometry is used to meet the mixing and oxygen transfer requirements of diffused aeration systems applied to the treatment of municipal wastewaters. As one of its characteristics, the plug flow configuration has a high organic loading at the influent end of the aeration basin. Loading is then reduced over the length of the aeration basin as the organic components of the wastewater are assimilated by the microorganisms. At the downstream end of the basin, oxygen consumption primarily results from endogenous respiration. However, this arrangement is not the actual configuration of the existing activated sludge process presently operated at Kohtla-Järve. Under the existing arrangement, the first bay of each reactor receives all the return activated sludge, while the influent wastewater enters the second and third bays through a distribution trough that divides the flow evenly within the available basin volume. These conditions create the following process-related deficiencies when treating the combined municipal and industrial wastewaters at Kohtla-Järve.

- Because the return activated sludge enters the process independent of the incoming wastewater, a condition of sludge stabilization (i.e., aerobic digestion) is produced that may result in a reduction of microbial activity and a lessening of the treatment of the various dissolved constituents present in the industrial wastewater sources.
- Introducing 50% of the influent wastewater into the third bay of the biological treatment reactor results in a shortening of the overall hydraulic residence time (HRT) of the process. This has the effect of providing less time for effective treatment, and the subsequent removal of the more persistent constituents in the wastewaters is reduced.

Because of its shortened HRT and low mixed liquor suspended solids (MLSS) concentration, the Kohtla-Järve biological wastewater treatment process is more sensitive to changes in hydraulic and/or BOD_7 loadings. These sensitivities have resulted in diminished performance and noncompliance with the "Helcom Recommendations."

The deficient performance of the activated sludge sedimentation tanks may have resulted from the inadequate design of clarifier inlet and outlet conditions. Because inlets should be designed to dissipate the inlet port velocity, distribute flow and solids equally across the cross-sectional area of the tank, and prevent short circuiting in the settling tank, a defective inlet design can result in both poor sedimentation (i.e., solids thickening) and wastewater clarification. Additionally, inadequate outlet structures will result in localized, high velocity gradients and short circuiting. If the velocity gradients reach the scour velocity, settled particles can be swept into the tank effluent.

Concentration and density differences between the influent and the tank contents significantly affect the hydraulic performance of the sedimentation tank. Density flow, rather than a high approach velocity, often causes sludge carry-over of the effluent weirs. Consequently, effluent should be withdrawn from a sedimentation tank in a manner that minimizes density currents. Typically, effluent is withdrawn from a sedimentation tank by an overflow weir into a launder or effluent channel. Weirs may be either straight edged or V-notched. The overflow weir must be level to control the water surface elevation in the sedimentation tank, and of sufficient length to promote uniform effluent withdrawal. The Kohtla-Järve sedimentation tanks use broad-crested weirs, approximately rectangular in cross-section. Such weirs are of restricted length and are not adjustable, which could result in an unleveling should structure deposition occur. Weir loadings on both the first- and second-stage activated sludge sedimentation tanks presently exceed 325 $m^3/m\text{-}d$ under average flow conditions. Weir loadings for the future regional treatment facility will exceed 570 $m^3/m\text{-}d$. Conventional design criterion recommends that weir loadings not be greater than 190 $m^3/m\text{-}d$ for activated sludge sedimentation tanks (Water Pollution Control Federation, 1985). However, engineering experience has led to a general consensus that higher weir loading rates may be acceptable if all other design considerations are met (Metcalf & Eddy, Inc., 1991).

Table 1

Performance of Existing Kohtla-Järve Biological Treatment Process[a]

Parameter	Influent Wastewater Concentrations[b]		Effluent Wastewater Concentrations[c]	
	Average	Range	Average	Range
Flowrate, m^3/day	31,257 ± 2,359[d]	27,776 - 35,574	–[e]	–[e]
Temperature, C	16.9 ± 3.5	13 - 22	15.8 ± 3.5	12 - 21
pH	7.6 ± 0.3	7.1 - 8.1	7.2 ± 0.3	6.6 - 7.5
Total[f] BOD_7, mg/L	205 ± 52	114 - 292	39.4 ± 13.3	19.2 - 62
Settled[g] BOD_7, mg/L	–	–	18.3 ± 6.6	10.1 - 29.2
Total BOD_{21}, mg/L	265 ± 78[h]	176 - 411	56 ± 24	33 - 112
Settled BOD_{21}, mg/L	–	–	25.4 ± 12.7	12.2 - 59.5
Total COD, mg/L	600 ± 58	526 - 695	306 ± 56	229 - 412
Settled COD, mg/L	–	–	182 ± 26	153 - 228
Volatile Phenols, mg/L	7.5 ± 1.8	5.3 - 10.6	0.1 ± 0.05	0.05 - 0.25
Total Phenols, mg/L	26.4 ± 5.3	16.7 - 34.4	4.1 ± 1.3	2.3 - 7.6
Total Nitrogen, mg/L	38 ± 2.9	32 - 42.7	25.5 ± 7.4	14.5 - 35.9
Ammonium-Nitrogen, mg/L	33 ± 3.6	26.8 - 38	16.0 ± 10.5	2.9 - 30.6
Nitrite-Nitrogen, mg/L	0.09 ± 0.09	0.03 - 0.4	3 ± 2.1	0.3 - 6.2
Nitrate-Nitrogen, mg/L	1.27 ± 0.34	0.63 - 1.9	4.2 ± 3.0	1.1 - 9.9
Total Phosphorus, mg/L	1.69 ± 0.3	1.27 - 2.25	1.1 ± 0.28	0.75 - 1.68
Settled Phosphorus, mg/L	–	–	0.35 ± 0.12	0.19 - 0.52

Parameter	Influent Wastewater Concentrations[b]		Effluent Wastewater Concentrations[c]	
	Average	Range	Average	Range
Oil, mg/L	24.2 ± 7.5	13.9 - 36.8	7.6 ± 3.9	1.0 - 13.8
Sulfates, mg/L	181 ± 48	121 - 269	171 ± 60	97 - 274
Sulfides, mg/L	1.9 ± 0.7	1.1 - 3.3	0.66 ± 0.25	0.25 - 1.25
Chlorides, mg/L	257 ± 33	203 - 318	234 ± 26	185 - 295
Suspended Solids, mg/L	82 ± 18	49 - 117	88 ± 25	46 - 136
Total Solids, mg/L	1249 ± 233	1004 - 1925	1161 ± 117	1012 - 1420

[a] Wastewater treatment performance data from October 1994 through November 1995.

[b] Influent wastewater concentrations are indicative of pretreatment for grit removal and primary solids separation.

[c] Effluent wastewater concentrations are indicative of the second stage of the biological treatment process.

[d] Based on advective flow, the overall average hydraulic residence time of the bioreactor system is 27.2 hours (i.e., assumes no dispersion and does not account for sludge recycle).

[e] Same as influent wastewater flowrate less the quantity of activated sludge wasted from the process.

[f] Total indicates parameter was measured with suspended solids present.

[g] Settled indicates parameter was measured after suspended solids were separated by gravity.

[h] Data are expressed as average ± one standard deviation from the mean (typical).

Table 2

Influence of Treatment Stage on Existing Biological Treatment Process Performance

Parameter	Influent Wastewater		Effluent First-Stage Biotreatment		Effluent Second-Stage Biotreatment	
	Average	Range	Average	Range	Average	Range
Total[a] BOD_7, mg/L	205 ± 52	114 - 292	155 ± 57[b]	69 - 255	39.4 ± 13.3	19.2 - 62
Settled[c] BOD_7, mg/L	–	–	82 ± 43	34 - 173	18.3 ± 6.6	10.1 - 29.2
Total BOD_{21}, mg/L	265 ± 78	176 - 411	207 ± 87	93 - 326	56 ± 24	33 - 112
Settled BOD_{21}, mg/L	–	–	108 ± 57	40 - 246	25.4 ± 12.7	12.2 - 59.5
Volatile Phenol, mg/L	7.5 ± 1.8	5.3 - 10.6	2.19 ± 1.64	0.34 - 5.0	0.1 ± 0.05	0.05 - 0.25
Total Phenol, mg/L	26.4 ± 5.3	16.7 - 34.4	12.6 ± 4.7	6.6 - 23	4.1 ± 1.3	2.3 - 7.6
Ash Content of Activated Sludge, %	–	–	13.9 ± 5.0	8.5 - 24.8	10.3 ± 1.8	8.0 - 13.4
Sludge Volume Index, mL/g	–	–	77 ± 19	50 - 115	79 ± 22	43 - 108
Average Hydraulic Residence Time, hrs	–		6.8		20.4	
Mixed Liquor Suspended Solids under Aeration[d], mg/L	–		1,000 - 1,500		2,000	
Treatment Stage Sedimentation Tank Underflow Solids[d], mg/L	–		2,000 - 4,000		5,000 - 6,000	
Estimated Food-to-Microorganism Ratio (Sludge Loading), $\frac{\text{mg } BOD_7}{\text{mg MLSS-d}}$	–		0.14		0.07	
Estimated Sedimentation Tank Hydraulic Loading, $m^3/d/m^2$	–		34.6		15.5	
Estimated Sedimentation Tank Solids Loading, $kg/hr/m^2$	–		2.36		2.49	
Estimated Sludge Recycle, m^3/d	–		20,860[e]		20,400	

[a] Total indicates parameter was measured with suspended solids present.
[b] First-stage biological process experiences 208 ± 71 mg/L suspended solids in the sedimentation basin overflow.
[c] Settled indicates parameter was measured after solids were separated by gravity.
[d] Information provided by L.I. Korolenko, Manager of Kohtla-Järve WWTP.
[e] Includes 8,590 m^3/d of underflow activated sludge from second-stage biological treatment process.

3 FUTURE REGIONAL WASTEWATER TREATMENT WASTE LOADINGS

The future waste loadings for the proposed regional wastewater treatment plant at Kohtla-Järve are presented in Table 3 at the end of this chapter. The future wastewater treatment plant will process 55,005 m^3/d of wastewater with an average BOD_7 loading of 21,519 kg/day and a suspended solids loading of 6,561 kg/day. This is a flow increase of 76% over the average existing WWTP dry weather hydraulic loadings, and a 236% increase in the current BOD_7 loads. Future total phosphorus and total nitrogen loadings will equal 177 kg/day and 2,558 kg/day, respectively. The future wastewater will provide all of the phosphorus and nitrogen needed for biomass synthesis, which will result in an 85% reduction of the overall waste total phosphorus and a 42% reduction of the total nitrogen load under average conditions. The projected wastewater chemistry of the future Kohtla-Järve WWTP suggests that the "Helcom Recommendations" for allowable effluent total phosphorus will be met by biomass synthesis requirements alone. However, an additional 33% removal of the influent wastewater, total nitrogen level may also be required to meet future "Helcom Recommendations" for the discharge of treated effluents to the Gulf of Finland. The future volatile phenol and total phenol loadings will equal 494 kg/day and 1,550 kg/day, respectively. This is a 110% increase in the volatile phenol and an 88% increase in the total phenol loadings on the existing wastewater treatment system at Kohtla-Järve.

The distribution of future waste loads to the Kohtla-Järve regional WWTP is presented in Table 4 by wastewater source. These data indicate that future municipal wastewater sources will account for 62.7% of the flow, but only 31.8% of the BOD_7 and 33.0% of the COD loads on an upgraded regional wastewater treatment plant. Municipal wastewater sources also account for 88% of the total phosphorus, 42.5% of the total nitrogen, and 58.6% of the suspended solids loadings on the future regional WWTP.

3.1 Carbonaceous Waste Loadings

The regional WWTP will receive 63.6% of its future BOD_7 loading from industrial wastewater sources, with Kiviter/Kiviõli oil shale operations accounting for more than half of this pollutant load. Kiviter/Kiviõli oil shale operations will also account for 33.1% of the overall COD pollutant load and 17.2% of the suspended solids load on the future regional WWTP.

The Kiviter/Kiviõli facilities are also responsible for 81% of the volatile phenol and 85.5% of the total phenol loading on the future Kohtla-Järve WWTP. This suggests that an improvement in dephenolization operations at the facilities would benefit the overall operation of the wastewater treatment system. However, most of the volatile phenol is derived from the Kiviter tar removal operations, which do not now have unit processes for the treatment of phenol-bearing wastes. Nevertheless, the activated sludge process at the regional WWTP has demonstrated considerable effectiveness for the degradation of the phenolic compounds in the Kiviter wastewater. It is well established that most monohydric and polyhydric phenols experience complete degradation during aerobic biological treatment.

Industrial wastewater sources from the Velsicol Eesti AS facility at Kohtla-Järve are estimated to contribute 21.3% of the future BOD_7 loading on the regional WWTP. The Velsicol wastewater sources presented in Table 3 include pollutant loads from the benzoic acid production plant and a benzoate esters unit at future production levels of 54,545 metric tons/year and 13,636 metric tons/year, respectively. The benzoic acid production wastewater pollutant loads are based on flow data provided by Velsicol Eesti AS and on pollutant constituent quality data obtained from Kiviter for this wastewater. The benzoate esters production pollutant loads are estimates of contaminant oxygen demand based on constituent quality data provided by Velsicol.

Benzoic acid at the Velsicol facility is produced by the oxidation of toluene in a two-stage, liquid phase batch catalytic process. The future benzoate esters production unit will produce glycol benzoates, such as esters of diethylene glycol and dipropylene glycol. This production facility is also a batch process where esters of dipropylene glycol are produced 80% of the time. The predicted pollutant loads for each production batch are shown in the table at the bottom of this page.

These data indicate that the probable concentration of BOD_7 in wastewaters from benzoate esters production will vary from 54,000 to 65,000 mg/L. (The estimates are based, in part, on data presented in Pitter and Chudoba [1990] for the BOD of specific organic compounds measured with the aid of mixed cultures of heterotrophic bacteria.) The chemical oxygen demand of the benzoate esters wastewater is assumed equivalent to the calculated theoretical oxygen demand and, as such, will vary from 82,400 to 99,100 mg/L. The design annual wastewater flow from the benzoate esters unit is 20,500 m^3 per year. Assuming an annual on-stream production period of 315 days, this yields a flowrate of 65 m^3/d, or less than 0.12% of the total average hydraulic load on the future regional WWTP.

The estimates for the chemical and biochemical oxygen demand of the benzoate esters wastewater should be confirmed with data from an actual sampling of a benzoate esters production facility. Velsicol should provide analytical data for COD, BOD_7, phenolics, total suspended solids, total dissolved solids, pH, and alkalinity of a typical benzoate esters production wastewater before the design of the new regional WWTP is finalized.

Given the high pollutant strength of the benzoate esters production wastewaters and that this waste stream is generated from batch operations, there is the requirement that Velsicol provide adequate source equalization and control to guarantee that their wastewater not enter the regional WWTP as short-duration, high concentration slugs of contaminant oxygen demand. The most appropriate method of controlling the impact of high-strength, low-volume wastewaters on biological treatment is to provide several days of storage capacity at the production facility so that effective equalization and neutralization of the wastewater can be achieved prior to discharge of the waters to the regional WWTP. This would also permit the opportunity to recover separable hydrocarbon liquids from the wastewaters should they be present in the waste stream at the time of production. The wastewaters would then be pumped at a constant rate from the facility equalization/ storage tank such that the waste load on the regional WWTP could be evenly distributed over a 24-hour day. This would require the metering of the benzoate esters wastewater discharges to the regional WWTP at approximately 45 liters/min, which should permit adequate opportunity for effective dilution by the commingling of this stream

Benzoate Ester	Theoretical Oxygen Demand (kg)	Estimated Biochemical Oxygen Demand (kg)	Wastewater Quantity (m^3)
diethylene glycol (B-245 production)	3,503.1	2,293.7	42.5
Dipropylene glycol (B-988 production)	4,348.9	2,868.5	43.9

with the other industrial and municipal waste sources.

In general, the options for pretreatment of the benzoate esters wastewater are limited because of the high organic pollutant content of this waste stream. Conventional wastewater treatment technologies such as activated carbon adsorption, biological treatment, and chemical oxidation are clearly not applicable without substantial dilution of the wastewater to effect a lowering of the COD. The only technology that would possibly be able to be applied directly to the treatment of the undiluted benzoate esters wastewater is catalytic wet oxidation (e.g., Nippon Shokubai Co., Ltd., NS-LC System). Catalytic wet oxidation is an oxidative degradation process that treats high COD wastewaters in a shell and tube reactor at high temperature and pressure in the presence of a catalyst. This technology can be quite efficient when a substantial quantity of wastewater containing more than 50,000 mg/L of COD is to be treated. The process could possibly offer a stable effluent quality and the advantage of heat recovery. If such a process can be applied to the treatment of the benzoate esters wastewater, the cost of treatment could be prohibitively expensive, both in terms of capital and operating costs. The installed costs for a catalytic wet oxidation system treating 45 liters/min of benzoate esters wastewaters would be between 2.5 and 3.0 million U.S. dollars. Therefore, the preferred option is to treat the benzoate esters wastewater in the Kohtla-Järve regional WWTP, taking advantage of the dilution provided by the other waste sources.

3.2 Nitrogen Waste Loadings

Industrial wastewater sources will be responsible for 55.0% of the future total nitrogen load on the regional WWTP, with wastewaters from Nitrofert operations accounting for approximately 50% of the industrial nitrogen load. The potential for improved nitrogen recovery at the Nitrofert facility should be investigated, since this would reduce the need for future retrofits of the regional WWTP to meet "Helcom Recommendations" for nitrogen removal from treated effluents. The "Helcom Recommendations" have as a long-term goal the achievement of a 75% reduction in the total nitrogen load from the Kohtla-Järve WWTP to the Gulf of Finland. This level of nitrogen removal will require that the regional wastewater treatment facility not only achieve biological nitrification of the combined municipal and industrial wastewaters, but also that it maintain effective biological denitrification operations in the activated sludge process while simultaneously treating high levels of influent carbonaceous BOD_7. In its present process configuration, the Kohtla-Järve biological WWTP would not be capable of maintaining this degree of nitrogen removal. Therefore, a more prudent approach would be to implement source treatment and/or control of nitrogen levels in the various industrial wastewaters entering the regional wastewater treatment plant. Because most of the nitrogen in the industrial wastewater sources would exist in the form of the ammonium ion, removal and recovery of the nitrogen may be accomplished by steam stripping (Castaldi and Ford, 1981; Nemerow and Dasgupta, 1991).

Ammonia and carbon dioxide are the principal dissolved gases in the industrial wastewaters. With the Kiviter/Kiviõli oil shale operations wastewaters, these gases probably originate during the retorting operation while other inorganic constituents such as carbonates and bicarbonates originate from contact between the retort water and raw or spent shale in the retort.

Experimental studies with the application of both air and steam stripping of retort waters have demonstrated that steam stripping will effectively reduce the ammonia and carbon dioxide concentrations present in the wastewaters. However, retort waters will cause foaming and fouling problems in a steam stripper, and this technology is generally not used for the removal of nitrogen from oil shale operations wastewaters.

The steam stripping process is used for pretreatment of wastewater streams from petroleum refineries, coal processing plants, and synthetic fuel plants. The process is capable of achieving the separation and recovery of ammonia from industrial wastewaters, such as sour waters generated during catalytic cracking and coking operations. It is also used extensively for wastewater pretreatment in the fertilizer production industry.

The Nitrofert nitrogen fertilizer (ammonia salts and urea) manufacturing operations at Kohtla-Järve are responsible for approximately 50% of the total industrial nitrogen load on the regional WWTP. Ammonia is the basis for the manufacture of all nitrogen fertilizers and is the most significant pollutant in the wastewater from this industry. The typical pretreatments for fertilizer manufacturing wastewaters include neutralization, stripping of ammonia, and lime precipitation. Given that steam reforming would be used to produce the ammonia at the Nitrofert facility, steam stripping would then be a cost-effective approach for reduction of the ammonium-nitrogen content of wastewaters from this industry. An ammonia stripper at the Nitrofert facility could potentially remove 250 metric tons of NH_3-N per year from the Kohtla-Järve influent wastewater. This would serve to bring the total nitrogen level of the final discharge from the regional WWTP to within the "Helcom Recommendations" for allowable nitrogen discharges to the Gulf of Finland.

Options for nitrogen control at the Nitrofert operations include the use of proprietary ammonia recovery processes to produce either anhydrous or aqueous NH_3 suitable for sales or further processing, or the destruction of the ammonia produced with a conventional steam stripper in the facility flare along with other waste gases (e.g., CO and H_2S) from the manufacturing process. The latter is probably the more cost-effective approach because the nitrogen levels in the 3,250 m^3/d of Nitrofert wastewater are too low to justify the costs of reclamation.

Table 3

Future Waste Loadings for Proposed Regional Wastewater Treatment Plant at Kohtla-Järve

Wastewater Sources	Flow (m^3/d)	BOD_7 (kg/d)	COD (kg/d)	Total Phosphorus (kg/d)	Total Nitrogen (kg/d)	Suspended Solids (kg/d)	Volatile Phenols (kg/d)	Total Phenols (kg/d)	Population
Municipal Wastewaters									
Kohtla-Järve	14,040	967	3,313	38	407	1,264	3.10	23	24,904
Kohtla-Nömme	405	79	243	1.01	12	105	0.97	5.75	3,030
Ahtme	8,400	2,470	4,940[a]	57	307	1,277	0.22	–	21,886
Jõhvi	7,500	2,955	5,910[a]	43	254	915	0.12	–	12,847
Kukruse	135	22	44[a]	0.28	2.55	7.15	0.01	–	753
Kiviõli	4,020	346	868	16	105	273	0.04	12	10,455
Total Municipal	34,500	6,839	15,318	155.29	1,087.55	3,841.15	4.46	40.75	73,875
Industrial Wastewater									
Kiviter Tar Removal	8,500	4,000	9,350	3.5	94	850	300	600	
Kiviter Dephenolization	1,000	2,000	3,500	0.5	400	50	70	500	
Kiviõli Oil Shale Plant	1,500	1,020	2,500	4.0	60	225	30	225	
Nitrofert	3,250	250	750	5.0	680	750	–	–	
Velsicol Eesti AS									
Benzoic Acid[b]	810	325	550	–	121	41	1.1	4.3	
Benzoate Esters[c]	65	4,255	6,450	–	–	–	–	4.3	
Kiviõli Industries	400	500	800	–	–	–	–	–	
Püssi PPK[d]	1,580	1,300	3,200	6.5	47	224	1.2	–	
Kohtla-Järve Power Plant	900	30	200	1.0	6	80	–	–	
Total Industrial	18,005	13,680	27,300	20.5	1,408	2,220	402.3	1,333.6	
Spent Shale Pile Runoff	2,500	1,000	3,750	0.75	62.5	500	87.5	175	
Total Wastewater Loads	55,005	21,519	46,368	176.54	2,558.05	6,561.15	494.26	1,549.35	

[a] Estimated from BOD_7/COD equal to 0.5.
[b] Waste loads adjusted for future benzoic acid production of 54,545 metric tons per year.
[c] Estimated from information provided by Velsicol Eesti AS for the new benzoate esters plant wastewaters.
[d] Town of Püssi and Mining pits of Aidu included with particle board manufacture wastewater.

Table 4

Distribution of Future Waste Loads in the Proposed Kohtla-Järve Regional Wastewater Treatment Plant

Wastewater Source	Flow (%)	BOD_7 (%)	COD (%)	Total Phosphorus (%)	Total Nitrogen (%)	Suspended Solids (%)	Volatile Phenols (%)	Total Phenols (%)
Municipal Wastewater Sources								
Kohtla-Järve	25.52	4.49	7.15	21.52	15.91	19.26	0.63	1.48
Kohtla-Nömme	0.74	0.37	0.52	0.57	0.47	1.60	0.20	0.37
Ahtme	15.27	11.48	10.65	32.29	12.0	19.46	0.045	–[a]
Jöhvi	13.64	13.73	12.75	24.36	9.93	13.95	0.024	–
Kukruse	0.25	0.10	0.09	0.16	0.10	0.11	0.002	–
Kiviõli	7.31	1.61	1.87	9.06	4.10	4.16	0.008	0.77
Total Municipal	62.73	31.78	33.03	87.96	42.51	58.54	0.91	2.62
Industrial Wastewater Sources								
Kiviter Tar Removal	15.45	18.59	20.16	1.98	3.67	12.96	60.70	38.73
Kiviter Dephenolization	1.82	9.29	7.55	0.28	15.64	0.76	14.16	32.27
Kiviõli Oil Shale Plant	2.73	4.74	5.39	2.27	2.35	3.43	6.07	14.52
Nitrofert	5.91	1.16	1.62	2.83	26.58	11.43	0.0	0.0
Velsicol Eesti AS[b]	1.59	21.28	15.10	0.0	4.73	0.62	0.22	0.56
Kiviõli Industries	0.73	2.32	1.73	–	–	–	–	–
Püssi PPK (Particle Board)	2.87	6.04	6.90	3.68	1.84	3.41	0.24	–
Kohtla-Järve Power Plant	1.64	0.14	0.43	0.57	0.23	1.22	0.0	0.0
Total Industrial	32.74	63.56	58.88	11.61	55.04	33.83	81.39	86.08
Spent Shale Pile Runoff	4.53	4.66	8.09	0.43	2.45	7.63	17.70	11.30
Total Wastewater	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[a] Indicates that data are not available for the wastewater source. Assumed negligible for this analysis.

[b] Includes waste loads from both the future benzoic acid production and the new benzoate esters production plants.

4 SPENT SHALE PILE RUNOFF

Waters applied to the spent shale piles (i.e., ash heaps) at the Kiviter facility presently runoff the piles into collection moats that convey the wastewater to the Purtse River and eventually to the Gulf of Finland. Table 3 indicates that the average daily runoff flowrate equals 2,500 m^3/d. Runoff flowrates from the ash heaps during periods of storm events and/or snow melt may achieve a maximum flow of 10,000 m^3/d. It is proposed that in the future these wastewaters be managed in a series of engineered ponds, generally termed "waste stabilization ponds." These ponds would be designed to retain the wastewaters until biological processes render them stable or until all degradable pollutant constituents have been removed, allowing discharge of the waters to the natural environment.

Three engineered ponds presently exist in the vicinity of the spent shale piles. Physical characteristics of the ponds are shown below. The ponds cover approximately 111 hectares of area and provide an effective hydraulic residence time (HRT) of 136 days at the maximum runoff flowrate. The smaller ponds would function as the primary treatment vessels, while the largest engineered pond would provide final effluent polishing. The primary treatment ponds would be equipped with a limited number of circulating aerators and floating curtain walls of vinyl-coated polyester or equivalent material. The floating curtain walls divide the ponds into compartments permitting plug or series flow through the basins. The ponds will function primarily as facultative waste stabilization ponds, with an aerobic surface and an anaerobic bottom where solids accumulate. The primary means of aeration is photosynthetic oxygenation.

The pollutant constituent characteristics of the spent shale pile runoff are presented in Table 5. The water strengths reported on Table 5 for the spent shale pile runoff are somewhat higher than those presented in Table 3. This difference may result from the considerable variability associated with this waste stream. These data indicate that this wastewater would be deficient in the quantity of available nitrogen and phosphorus needed to sustain microbiological purification. However, the eutrophied conditions that generally exist in waste stabilization ponds result in the cycling of nutrients through the simultaneous processes of growth and decay of algae. These processes are affected by insulation and radiation, temperature and thermal gradients, pond geometry, wind, gas exchange, and seeding. The biochemical activity involves typical carbon, nitrogen, sulfur, and phosphate transformations, as well as more subtle reactions. Hence, after an initial adjustment of pH, seeding of microorganisms, and addition of nutrient supplements to the pond waters,

Pond	Volume	Surface Area	Depth
1	208,700 m^3	87,000 m^2	2.4 m
2	215,200 m^3	93,000 m^2	2.3 m
3	932,800 m^3	930,000 m^2	1.0 m

the stabilization processes may proceed without additional amendment as the system matures.

In theory, the stabilization pond system is to act as the principal treatment process for management of the spent shale pile runoff water. However, in practice it is not certain that this engineered pond treatment strategy will continuously meet the "Helcom Recommendations" for treated effluents to the Gulf of Finland. Pond systems are most effective in the removal of particulate carbonaceous BOD through the mechanisms of sedimentation and solids stabilization in pond sediments. However, the algae produced in the facultative ponds will also contribute to the suspended solids level of the final discharge. During periods of maximum algae growth, effluent suspended solids would most probably exceed the "Helcom Recommendations" for treated effluent quality.

It is clear, nevertheless, that the waste stabilization ponds will effectively provide flow equalization and storage for the ash heap runoff water. The ponds also will provide suspended solids removal and some degree of carbonaceous BOD_7 removal, making the spent shale pile runoff more amenable to biodegradation in the Kohtla-Järve wastewater treatment plant. Therefore, the ponds are viewed as an effective pretreatment of the spent shale pile runoff to be used prior to the commingling of this wastewater source with the other industrial waste streams at the WWTP. It is recommended that the treated effluents from the stabilization pond system be diverted to the regional WWTP for additional treatment prior to final discharge of the ash heap runoff to the Gulf of Finland. This should be done until which time it is determined that the pond treatment system alone can meet the "Helcom Recommendations" for treated effluent quality.

Table 5

Spent Shale Pile Runoff Characterization[a]

Parameter	Average Concentration	Concentration Range
BOD_7, mg/L	1,480	810 - 2,700
COD, mg/L	2,810	1,950 - 4,600
Volatile Phenols, mg/L	65	50 - 100
Total Phenols, mg/L	155	134 - 230
Total Phosphorus, mg/L	0.4	0.1 - 1.4
Suspended Solids, mg/L	257	120 - 350
Total Nitrogen[b], mg/L	34.5	26.8 - 45.0
Ammonium-Nitrogen, mg/L	19.6	10.3 - 30.9
Nitrite-Nitrogen, mg/L	0.2	0.1 - 0.3
Nitrate-Nitrogen, mg/L	2.6	<0.1 - 4.7
pH	12.4	11.8 - 13.3

[a] Data obtained from Oy Vesi-Hydro AB report entitled "Wastewater Treatment in the Kohtla-Järve Area" dated February 5, 1993.

[b] Analysis by the Kjeldahl Method.

5 OPTIONS FOR IMPROVEMENT OF THE REGIONAL WASTEWATER TREATMENT PLANT

Previous sections of this report focused on the process deficiencies inherent in the design of the existing Kohtla-Järve regional wastewater treatment plant; the waste loads associated with the future combined municipal and industrial wastewater sources; and the pretreatment strategy recommended for management of the ash heap runoff waters. This section will address the possible options for improvement of the regional WWTP to meet the future waste loads such that the effluents will comply with the "Helcom Recommendations" for discharge to the Gulf of Finland.

5.1 Basis-of-Design Considerations

Treatability studies, with composite wastewaters similar (with some exceptions) in quality to that derived from the municipal and industrial wastewater sources presented in Table 3, were conducted by Oy Vesi-Hydro AB in 1992. These activated sludge process treatability tests generated the data summarized in Table 6. Included among these data are the values of a number of activated sludge process design parameters obtained from bench-scale bioreactor studies with the Kohtla-Järve regional wastewater. These include HRT, sludge age (mean cell residence time), sludge (biomass) production, food-to-microorganism ratio (sludge loading), and sludge volume index (SVI). These data were obtained for biological wastewater treatment of the combined wastewaters both with and without spent shale pile runoff water.

The test bioreactors used in the treatability studies were two-chamber complete-mix reactors. One bioreactor had chambers of equal volume, while in the other the first chamber was one-half of the volume of the second. Both bioreactors used fine-bubble pipe aeration. Although staged, these bioreactors were essentially completely-mixed vessels in which the content of each chamber had uniform characteristics throughout the entire stage. In this configuration, influent wastewater and return activated sludge are rapidly distributed throughout the first-stage aeration basin and the operating characteristics of MLSS, microbial respiration rate, and soluble BOD_7 are uniform throughout. Since the body of the chamber liquid has the same quality as the chamber effluent, there exists a low concentration of substrate available at any time for a relatively large mass of microorganisms under aeration. This characteristic is the reason why a complete-mixed activated sludge process can handle wide variations in organic loading and toxic shocks (to a limited extent) without producing a change in effluent quality (Castaldi, 1988; De Renzo, 1980).

Although the treatability study reactors experienced variable solids carry-over during the individual test periods (Table 6), performances for BOD_7 and COD removals were reasonably good even at relatively short HRTs. (It is probable that a further reduction in the concentration of effluent suspended solids would produce improved effluent qualities for both BOD_7 and COD to acceptable discharge levels as was discussed in an earlier section of this report.) Treatment performance was generally poorer when the spent shale pile runoff water was present in the wastewater mixture. However, increasing both the process HRT and mean cell residence time seems to affect improved treatment across the biological reactors even when high percentages of ash heap water are present in the combined municipal and industrial waste streams.

Two-stage activated sludge treatment (i.e., two reactor/clarifier systems in series) does not appear to be necessary for effective treatment of the Kohtla-Järve regional wastewaters. This is intuitively correct because the traditional reason for a two-stage activated sludge design is the maintenance of two distinctly different microbial populations (e.g., heterotrophic and autotrophic bacteria) which have different functions in the process (e.g., phenol degradation and nitrification). Because nitrifiers exist together with most carbon-utilizing bacteria, the optimum conditions for nitrification are more a function of the system sludge age and the operating mixed liquor temperature, which are also parameters of concern with carbonaceous BOD_7 removal.

Although interpretation of the Vesi-Hydro treatability results is somewhat subjective, it seems reasonable to assume that the biological treatment process at Kohtla-Järve should be designed to maintain a sludge loading (F/M) of less than 0.2 mg BOD_7/mg MLSS-d and a HRT greater than 12 hours when treating a combined regional wastewater that also contains spent shale pile runoff. The mean cell residence time (sludge age) of the process should be greater than 10 days for effective carbonaceous BOD_7 removal. Moreover, longer sludge ages may be necessary to affect biological nitrification within the activated sludge process when treating these wastewaters.

5.2 Process Improvements

The premise used in the analysis of options for improvement of the wastewater treatment process at Kohtla-Järve is that existing equipment and appurtenances, to the extent practicable, can be modified to effect an upgrade of the treatment works to meet future waste loads. The assumptions used to form the basis of the recommendations for process improvement are as follows:

- The preliminary treatment facilities (e.g., comminutors) at the Kohtla-Järve WWTP require upgrading or replacement. It is recommended that these facilities be replaced with bar-type screens.
- The primary treatment facilities (e.g., primary sedimentation tanks) at the Kohtla-Järve WWTP require upgrading because they are undersized for the future hydraulic loads. It is recommended that the two existing (presently unused) tertiary circular settling tanks be converted to primary sedimentation tanks.
- Two-stage activated sludge treatment offers no particular process advantage in the treatment of the combined municipal and industrial wastewaters from the Kohtla-Järve region.
- The existing equalization basin and first- and second-stage aeration basins at the Kohtla-Järve WWTP provide adequate capacity to meet the hydraulic residence time requirement for treatment of the future waste loads on the regional facility.
- The existing second-stage activated sludge sedimentation tanks can be improved and upgraded to provide adequate sludge thickening and clarification capacity for the modified biological treatment process. However, the upgraded activated sludge final sedimentation tanks will not meet the effluent suspended solids requirement of 15 mg/L or less. The likely solids concentrations in the overflow of these tanks will vary from 20 to 30 mg/L.
- The existing activated sludge process can be improved and upgraded by taking the following process modification actions:

    - Convert to a single-stage system.
    - Change the configuration of the existing aeration basins to complete mix activated sludge.

- ☐ Convert the existing first-stage activated sludge sedimentation tanks to aerobic/anaerobic contact reactors for improved nitrogen removal.
- ☐ Modify the existing return activated sludge conveyance system to permit simultaneous mixing of influent wastewater and active biomass in the newly configured aeration basins.

- The existing fine-bubble, porous diffuser aeration system should be adequate for meeting the oxygen demand of the future regional WWTP. Porous diffuser systems are high-efficiency aeration systems (SOTE: 13-40%) that provide good operational flexibility. Although a portion of the existing ceramic plate diffusers at the Kohtla-Järve WWTP are broken or otherwise dislodged, retrofits are continually being installed. Some rearrangement of the location of the diffusers in the individual aeration basins may be necessary to improve mixing and aeration efficiency. This should be evaluated as the retrofits are installed. Nevertheless, it is more cost-effective to continue these repairs than to replace the entire aeration system with new diffusers or alternate aeration devices.
- Adequate air compressor capacity exists at the Kohtla-Järve WWTP to meet the future mixing and aeration requirements of the upgraded facility.
- Granular media filtration of activated sludge process final sedimentation effluent is needed to meet the suspended solids requirement of the "Helcom Recommendations" for effluent discharge to the Gulf of Finland.

All of the above assumptions were verified by engineering calculations and/or vendors consultations.

The recommendations for improvement of the Kohtla-Järve regional wastewater treatment plant to meet future waste loads are presented in Table 7. The proposed process improvements mostly utilize the existing wastewater treatment equipment and appurtenances at the WWTP. This equipment would be modified and/or upgraded to comply with established design criteria for industrial/municipal wastewater treatment. The improvements are presented by treatment function, with the following process areas identified:

- Municipal wastewater preliminary and primary treatments;
- Industrial wastewater preliminary treatments; and
- Combined municipal and industrial wastewater secondary and tertiary treatments.

The improvements outlined in Table 7 require the addition of several new items of wastewater treatment equipment. These include manually and mechanically cleaned bar screens, activated sludge return pumps, and tertiary granular media filters. Additionally, a polymer feed system will be required to provide polyelectrolyte to the mixed liquor activated sludge to assist in sludge thickening during secondary (i.e., final) sedimentation. The existing ferric sulfate feed system (required to ensure adequate phosphorus reduction) could remain in service and be used as needed to meet the "Helcom Recommendations."

The bar screens were preferred over the existing comminutors (which are not functional) because of their simplicity and durability. These units will serve to remove municipal and industrial wastewater debris (e.g., rags, sticks, wood particles), which has caused operation and maintenance problems in the past with downstream unit processes at the Kohtla-Järve WWTP.

The manually cleaned 100 mm opening bar screens (trash racks) are to be positioned upstream of the mechanically cleaned 25 mm opening bar screens to reduce the loading of trash and heavy debris that may accumulate on the cable-driven raking mechanism of the continuous self-cleaning screen and cause bottom jamming. Mechanical cleaning, compared with manual cleaning, will reduce labor cost, improve flow conditions and screening capture, reduce nuisance odors, and better handle large quantities of wastewater debris and screenings.

The process modification proposed for the activated sludge system at Kohtla-Järve requires the use of return activated sludge pumping to transfer sludges from the final sedimentation tanks to the aeration basins. Approximately 28,000 m^3/d of return activated sludge at 10,000 mg/L will need to be pumped to the head end of the activated sludge process aeration basins to meet the sludge loading requirements of the improved biological treatment process. The existing air lift pumps on each clarifier will be used to lift the sludge from the bottom of the final sedimentation tanks, enabling it to be conveyed to centrally located wet wells. These wet wells would be provided with positive displacement or centrifugal-type sludge pumps that would be used to transfer the activated sludge to the existing aeration basins or the facility equalization basins, if the process is modified to achieve enhanced biological nitrification.

Air lift pumps are commonly used for return and waste activated sludge transfers from secondary clarifiers and for lifting grit from the bottom of grit chambers. The pump consists of a vertical pipe with its lower end submerged. Compressed air admitted to the bottom of the pipe reduces the average density of the mixture relative to the liquid outside of the pipe. Thus, at the proper air/liquid ratio, the liquid rises to the desired elevation.

Employing the existing air compressor capacity at the Kohtla-Järve WWTP, air lift pumps may be used to raise thickened activated sludge from the bottom of the final sedimentation tanks. The sludge is then conveyed through low head loss transfer channels to strategically placed return activated sludge pumping stations for final transport to the aeration basins.

Air lift pumps are relatively inexpensive to install, maintain, and operate. Although simple, these pumps provide minimal turndown capacity. Generally, when the flow is reduced by throttling the air supply, air lift pump operation becomes erratic, velocities decrease, and clogs develop.

The decision to retain the existing fine bubble, porous diffusers is based on the body of data in the United States and Europe which supports the effectiveness and efficiency of fine pore aeration systems in activated sludge applications (U.S. Environmental Protection Agency, 1989). What is at issue with the existing ceramic plate diffusers is their age and state of repair. These diffusers need repair and upgrading in selected aeration basins. Improvements are also needed in the maintenance procedures used to keep the aeration system operating efficiently. However, there are no process-related reasons which would justify abandonment of the fine bubble, porous diffusers. With proper maintenance, fine pore aeration systems are generally considered one of the most efficient aeration methods for activated sludge applications in use for municipal and industrial wastewater treatment.

Alternate aeration devices, such as aspirating-type aerators may also be appropriate in this application. However, the apparent high oxygen transfer efficiency and lower power requirements reported with these aeration devices depend on the application. Aeration devices such as the CELPOX aerator have been applied where nitrogen removal from municipal wastewater was the primary objective. In these systems, a portion of the activated sludge process is permitted to go anaerobic, and, consequently, fewer aerators are required per unit volume of aeration basin. This inevitably results in a low power level per gallon of wastewater treated. At the Kohtla-Järve WWTP, 63.6% of the future BOD load will come from the industrial sources, and the pollutants in these wastewaters are not biodegradable under anaerobic conditions. Consequently, it seems reasonable that the required input power levels would be higher than vendor claims made for the CELPOX aerators. Therefore, the CELPOX aerators may not be much more efficient than the repaired and well maintained fine pore aeration system already in use at Kohtla-Järve.

Aeration devices like the CELPOX aerators transfer oxygen to wastewater by bringing outside air at ambient temperatures into the activated sludge aeration basin. During the winter months, this will eventually cause a cooling of the aeration basin operating temperature, which will result in a decrease in the rate of biodegradation of the constituents in the wastewater. On the other hand, porous diffuser systems using compressed air will actually add heat to the activated sludge and result in operation at more optimum mixed liquor temperatures in the biological process such that biodegradation will proceed at a more rapid rate. This is important because treatment performance for short-residence time systems like the Kohtla-Järve activated sludge process are usually adversely impacted by cooler temperature operation.

The proposed modification of the final sedimentation tanks must be considered integrally with that of the aeration basins and return sludge pumping facilities. Area and depth requirements directly depend on settleability of the mixed liquor, average and peak wastewater flowrates, and return sludge pumping rates. Since steady-state operating conditions seldom occur, fluctuations in wastewater flowrate, MLSS concentration, and settleability require conservatism in design to maintain performance during process upsets. The proposed criteria for improved design of these tanks (Table 7) specified a maximum allowable solids loading for average flow conditions, an allowable SVI, and a maximum allowable weir loading rate. These conditions can be met only if existing tank inlet and outlet structures are modified.

The need to recover more dense underflow solids from the final sedimentation tanks led to the recommendation that a modification to the existing mechanism for sludge removal be considered for implementation as a future tank improvement (Table 7). This option involves the conversion of the existing chain and flight sludge collectors to two-tray multilevel chain and flight sludge removal mechanisms (Kelly, et al., 1995). It may also be necessary to modify the existing sludge hoppers in the rectangular tanks to improve solids capture and conveyance.

The addition of granular media filtration of activated sludge process final sedimentation effluent is required to meet the "Helcom Recommendations" for effluent suspended solids. It is proposed to use dual media, sand and anthracite, gravity filters to remove effluent suspended solids. When filtering conventional activated sludge effluents, granular media filtration can achieve from 3 to 10 mg/L suspended solids in process effluents without chemical coagulation. However, more frequent backwashes will be necessary if the solids carry-over from the activated sludge final sedimentation tanks is greater than 30 mg/L suspended solids. Hence, the requirement for upgrade of the final sedimentation tanks is paramount to the success of the proposed design.

Because it is not desirable to take a filter out of service often nor to use excessive amounts of washwater, a means to clean it easily and quickly is essential. Consequently, the preferred tertiary effluent filtration technology for this application is the Automatic Backwash (ABW) Rapid Granular Media Filter (Infilco Degremont Inc.). These filters have been used for the filtration of effluents from both industrial and municipal activated sludge treatment processes.

The automatic backwash filter takes advantage of surface filtration to operate at low head losses of 150 to 250 mm of water. This low head design reduces construction and maintenance costs and allows simpler basin and piping designs. To operate at a low head, the ABW filter is cleaned automatically, at relatively frequent intervals. In this filter design, the bed is divided into a number of compartments and an automatic mechanism is used to backwash and clean individual compartments sequentially, while leaving the rest in service to continue filtering.

Backwashing is initiated at a head loss increase of 50 to 150 mm of water over clean bed conditions. Once initiated, backwashing progresses from one end of the filter bed to the other with all but the compartment being backwashed remaining in service. Backwashing typically occurs once every two to six hours, and each compartment is backwashed for approximately 30 seconds.

Water for backwashing will come from stored treated (filtered) effluents, and spent backwash waters will be sent to the WWTP equalization tanks for treatment with influent wastewaters.

The proposed tertiary effluent granular media filtration system presented herein would require less than 7% of the surface area specified for implementation of the Vesi-Hydro circular post-sedimentation basins, as described in their proposal for expansion of the WWTP at Kohtla-Järve. The backwash water requirements for implementation of tertiary effluent granular media filtration would be less than 3.5% of the average influent wastewater flowrate.

Budgetary cost estimates for selected equipment items recommended for installation in the improved Kohtla-Järve regional wastewater treatment plant are presented in Table 8. Cost estimates are provided for manually and mechanically cleaned bar screens, activated sludge aeration basin and final sedimentation tank upgrades, gravity filtration of secondary effluents, and supporting pumping and chemical feed systems. The equipment costs are based on vendor estimates for the internals used in each of the unit processes. These are equipment costs; the costs for installation of the treatment equipment are not shown in Table 8, rather, estimates are provided for the amount of labor and concrete needed to erect the treatment processes once the equipment is in Estonia. These costs should be considered preliminary and may change after detailed engineering drawings are developed for each of the unit processes.

Table 6

Results of Biological Process Treatability Studies with Kohtla-Järve WWTP Wastewaters[a]

Spent Shale Pile Runoff (%)	Hydraulic Residence Time (hrs)	Mean Cell Residence Time (days)	Sludge Loading (mg BOD_7/ mg MLSS-d)	SVI (mL/g)	Sludge Production (g SS/kg BOD_7)	BOD_7[b] Remaining (mg/L)	COD[c] Remaining (mg/L)	Effluent Suspended Solids (mg/L)
0	6.3	3.5	0.48	140	600	16	209	33
0	5.5	4.8	0.38	193	560	13	209	24
0	10.0	8.6	0.23	68	510	12	168	29
0	16.7	12.5	0.19	78	420	11	143	28
3.5	9.7	4.7	0.38	83	600	32	256	99
5	7.1	3.1	0.47	165	730	37	256	27
5	6.8	2.6	0.55	222	730	27	276	32
5	15.8	12.0	0.17	76	510	17	258	50
7	8.7	4.1	0.48	86	540	22	209	70
10	12.3	13.2	0.17	53	460	20	247	62
10	15.2	–	0.13	73	–	30	232	88
10	15.2	12.6	0.15	58	560	26	237	92
20	12.5	9.0	0.25	59	490	27	277	92

[a] Data obtained from Oy Vesi-Hydro AB report entitled "Wastewater Treatment in Kohtla-Järve Area" dated February 5, 1993.
[b] Influent BOD_7 of wastewaters without spent shale pile runoff varied from 260 to 520 mg/L, while wastewaters that contained spent shale pile runoff averaged 415 $\pm$ 71 mg/L.
[c] Influent COD of wastewaters without spent shale pile runoff varied from 440 to 840 mg/L, while wastewaters that contained spent shale pile runoff averaged 808 $\pm$ 143 mg/L.

Table 7

Recommendations for Improvement of the Kohtla-Järve Regional Wastewater Treatment Plant

Proposed Treatment Process Improvements	Criteria for Improved Design
Municipal Wastewaters	
Manually cleaned bar screen 100 mm openings with bars set 30 to 45 degrees from the vertical.	• $q_{max} = 4{,}300$ m^3/hr
Mechanically cleaned bar screen 25 mm openings with bars set 0 to 30 degrees from the vertical.	• $q_{max} = 4{,}300$ m^3/hr
Grit Removal	
– Two (2) existing vortex grit removal tanks. Units may require high-pressure agitation water or air to remove compacted and clogged grit from sump.	• $Q_{design} = 40{,}000$ m^3/d, each unit for a total capacity of 80,000 m^3/d
Primary Sedimentation	
– Two (2) existing primary circular (18 m diameter) settling tanks. – Two (2) existing tertiary circular (18 m diameter) settling tanks to be used as primary sedimentation basins for municipal wastewaters. Dual or multi-weir cantilevered or suspended launders are recommended as future improvements.	• $Q_{design} = 34{,}500$ m^3/d • Hydraulic loading 33.9 $m^3/d/m^2$ • Weir loading 152.5 $m^3/m\text{-}d$ • HRT 2.7 hours • $Q_{peak} = 103{,}500$ m^3/d • Weir loading at peak flow < 500 $m^3/m\text{-}d$ • Hydraulic loading at peak flow < 120 $m^3/d/m^2$
Industrial Wastewaters	
Manually cleaned bar screen 100 mm openings with bars set 30 to 45 degrees from the vertical.	• $q_{max} = 1{,}500$ m^3/hr
Mechanically cleaned bar screen 25 mm openings with bars set 0 to 30 degrees from the vertical.	• $q_{max} = 1{,}500$ m^3/hr
Combined Wastewaters	
Wastewater Equalization Basins	
– Six (6) existing tanks at 3,492 m^3 each, for a total volume of 20,952 m^3. Continue providing aeration for mixing. Proposed future operation will provide for return activated sludge addition to these basins.	• $Q_{design} = 55{,}005$ m^3/d • HRT 9.14 hours • Aeration capacity should provide 25.4 $m^3/min/m^3$ tank for mixing
Activated Sludge Process Reactors	
– Four (4) existing first-stage bioreactors at 2,217.6 m^3 each, for a total volume of 8,870.4 m^3. – Four (4) existing second-stage bioreactors at 6,652.8 m^3 each, for a total volume of 26,611.2 m^3.	• $Q_{design} = 55{,}005$ m^3/d • HRT 16.64 hours without nitrification • HRT 25.78 hours for nitrification

Table 7 (Continued)

Proposed Treatment Process Improvements	Criteria for Improved Design
– Sixteen (16) existing first-stage sedimentation tanks at 165.6 m^3 each, for a total volume of 2,649.6 m^3 will be converted to activated sludge process reactors. Option to operate under anaerobic or aerobic conditions. Providing a total bioreactor volume of 38,131.2 m^3. Option of including equalization basin capacity of 20,952 m^3 to provide a total bioreactor volume of 59,083.2 m^3 to achieve biological nitrification.	• Aeration capacity should provide 25.4 $m^3/min/m^3$ tank for mixing • MLSS = 3,500 mg/L • Sludge age = 10.1 days minimum • Activated sludge recycle ratio 50% • Sludge load (F/M) 0.16 mg BOD_7/ mg MLSS-d without nitrification • Sludge load (F/M) 0.10 mg BOD_7/ mg MLSS-d for nitrification
– Use two (2) existing compressors throttled to provide 45,000 m^3/hr each, for a total of 90,000 m^3/hr to supply air to all aeration basins and the equalization basins.	• SOTE > 13%
– Utilize existing fine-bubble porous diffuser system, repaired and upgraded as appropriate, to aerate and mix all activated sludge basins. Option to use aspirating aeration device (e.g., CELPOX Aerators) in the converted first-stage sedimentation tanks for mixing and aeration.	
– The aeration basins will be modified for complete-mix activated sludge treatment. Return activated sludge and influent wastewaters will be combined at the existing wastewater distribution troughs in each of the first-stage aeration basins to achieve a uniform sludge/wastewater mixture in the reactors. Each aeration basin will require an appropriate modification to permit adequate mixing and blending of the return activated sludge and influent wastewater. The option to combine the return activated sludge and influent wastewater in the existing equalization basin is also recommended.	
Activated Sludge Process Final Sedimentation	
– Sixteen (16) existing second-stage sedimentation tanks at 289.8 m^3 each, for a total volume of 4,636.8 m^3 will be used to provide settling and clarification of the biologically treated wastewaters. Modification of the inlet structures are proposed to distribute flow evenly in both the vertical and horizontal directions. Effluent structures will also be modified to reduce weir loadings by using launders that extend 25 to 30% of the tank length from the effluent end. Option to modify the sludge collection system of each clarifier to a two tray design. Sludge will be transferred by airlift to central collection sumps and then pumped back to the head of the activated sludge reactors.	• Q_{design} = 55,005 m^3/d • Hydraulic loading 27.2 $m^3/d/m^2$ • Weir loading < 190 $m^3/m\text{-}d$ • Solids loading < 142.9 kg MLSS/m^2-d • SVI < 150 mL/g

Table 7 (Continued)

Proposed Treatment Process Improvements	Criteria for Improved Design
Gravity Filtration of Activated Sludge Process Final Sedimentation Effluent	
– Proposed to use dual media, sand and anthracite, gravity filters to remove particulate carbonaceous BOD_7 and residual insolubilized phosphorus from biological treatment system effluent. The total required filter area is 374.5-468.0 m^2, and the backwash water volume is 1,498-1,872 m^3/day or less than 3.5% of the influent wastewater flow rate. Water for backwash will come from stored treated effluents, and spent backwash waters will be sent to the WWTP equalization basins for treatment with influent wastewaters.	• Q_{design} = 55,005 m^3/d • Hydraulic loading 1.36-1.7 L/sec/m^2 filter • Backwash volume 4,000 L/m^2 filter

6 OTHER CONSIDERATIONS

The evaluation of technical options for improvement of the wastewater treatment system in the Kohtla-Järve region did not include the following:

- Options for treatment and disposal of waste sludges produced by the WWTP when operating at future design loads. (Average waste sludge production may exceed 15,300 kg/d [dry weight] at the future wastewater treatment facility.)
- Options for removal of total nitrogen present in the combined municipal and industrial wastewaters to levels consistent with the "Helcom Recommendations."
- Options for repair and upgrade of the existing treated effluent pipeline and deep-water outlet to the Gulf of Finland.

The above considerations were beyond the scope of this task.

Table 8

Budgetary Cost Estimate for Improvement of the Kohtla-Järve Regional Wastewater Treatment Plant

Equipment Items[a]	Equipment Cost[b] in 1995 U.S. Dollars	Installation, Labor, and Materials for Estonian Construction[c]
Manually cleaned bar screens for municipal and industrial wastewaters.	$75,000	200 manhours and 50 m^3 of concrete for discharge channel construction.
Mechanically cleaned bar screens with controls for municipal and industrial wastewaters.	$220,000	250 manhours and 50 m^3 of concrete for discharge channel construction.
Primary sedimentation tank upgrades including modification of outlet structures and retrofit and repair of sludge collection mechanisms. (Inclusive of the conversion of existing tertiary circular settling tanks to primary sedimentation tanks.)	$285,000	700-1000 manhours for tank modifications.
Auxiliary municipal wastewater pumping.	$50,000	250 manhours and 75 m^3 of concrete for pump station construction.
Activated sludge aeration basin upgrades excluding porous diffuser system retrofit and repair.[d]	–	2,000-2,500 manhours and 250-350 m^3 of concrete for basin modifications.
Final sedimentation tank upgrades including modification of inlet and outlet structures and upgrade of chain and flight sludge removal mechanisms.	$450,000	1,000-1,500 manhours and 200-250 m^3 of concrete for tank modifications.
Gravity filtration of final sedimentation tank effluent.	$540,000[e]	1,400 manhours and 500 m^3 of concrete for filter system construction.
Return activated sludge pumping.	$36,000	250 manhours and 50 m^3 of concrete for pump station construction.
Backwash filter pumping.	$25,000	250 manhours and 50 m^3 of concrete for pump station construction.
Polymer feed system for final sedimentation tanks.	$11,000	150 manhours for polymer feed system construction.

[a] Items include piping, valving, control systems, and other associated appurtenances required for operation of the selected equipment.

[b] Costs are exclusive of engineering design, equipment installation, and equipment start-up costs.

[c] Conveyance piping is not included in material estimates.

[d] Level of effort includes only aeration basin modifications. Engineering design activities are not included. The costs for removal and repair and/or replacement of the damaged portions of the aeration system are not estimated.

[e] Cost estimate based on the use of an automatic backwash filter, complete with compartmented filter bed, sectionalized underdrain, effluent and backwash ports, washwater hood, washwater trough, drive motor, traveling backwash mechanism, and pressure control devices.

7 CONCLUSIONS

The evaluation of technical options for improvement of the Kohtla-Järve wastewater treatment system led to the following conclusions.

- The existing WWTP does not now meet the treated effluent discharge requirements of the "Helcom Recommendations." This results from a combination of process configuration and equipment-related deficiencies which have prevented the WWTP from achieving wastewater treatment levels consistent with available capacity.
- Biological treatment alone will not be capable of meeting the future "Helcom Recommendations" for total nitrogen. Therefore, it is recommended that source treatment and/or control of nitrogen levels in the various industrial wastewaters entering the regional wastewater treatment plant be implemented. Control of nitrogen discharges from the Nitrofert operations is recommended because this stream accounts for approximately 50% of the total industrial nitrogen load. Because most of the nitrogen in this industrial wastewater source exists as the ammonium ion, removal and recovery of the nitrogen may be accomplished by steam stripping.
- Velsicol Eesti AS should provide adequate storage capacity at the benzoate esters production facility to achieve effective equalization and neutralization of the wastewater prior to its discharge to the regional WWTP. This should permit adequate opportunity for effective dilution by commingling of the benzoate esters wastewater with other industrial and municipal waste sources, hence reducing the impact of this waste source and making the benzoate esters wastewater more amenable to effective biodegradation in the regional WWTP.
- The diversion of spent shale pile runoff to engineered waste stabilization ponds is viewed as an effective pretreatment of these wastewaters prior to commingling with other industrial waste streams at the regional WWTP. This should be done until which time it is determined that the pond treatment system alone can meet the "Helcom Recommendations" for treatment of ash heap runoff water.
- Improvement of the WWTP at Kohtla-Järve requires the upgrade of existing preliminary and primary treatment systems; the modification of the existing activated sludge treatment process to a complete-mix process configuration; conversion to single-stage activated sludge treatment; modification of the existing return activated sludge conveyance system; and upgrade of the existing second-stage (final) activated sludge sedimentation tanks.
- It is more cost-effective to continue repairs and retrofits of the existing fine-bubble, porous diffuser aeration system than to replace the entire aeration system with new diffusers or alternate aeration devices. Adequate air compressor capacity also exists at the Kohtla-Järve WWTP to produce air for future activated sludge mixing and aeration requirements.
- Granular media filtration of activated sludge process final sedimentation effluent will be necessary to meet the "Helcom Recommendations" for effluent suspended

solids. However, this approach is more cost-effective than the expansion of the final sedimentation tank capacity (i.e., post-sedimentation basins) recommended by Oy Vesi-Hydro AB.

8 REFERENCES

Castaldi, F.J. "Biological Treatment of Wastewaters from Petrochemical Production." Presented at Enviro Tech 88, 3rd International Conference on Industrial Pollution Control and Safety, Bombay, India, September 1988.

Castaldi, F.J. and D.L. Ford. "Treatment Process Design Considerations in the Removal of Contaminants from High-Btu, Coal Gasification Wastewaters." Presented at the 54th Annual Conference of the Water Pollution Control Federation, October 1981.

De Renzo, D.J. *Biodegradation Techniques for Industrial Organic Wastes.* Noyes Data Corporation, Park Ridge, New Jersey, 1980.

Kelly, K.F.; D.P. O'Brien; W. McConnell; and J. Morris. "Two-Tray Clarifiers Yield Positive Results." *Water Environment & Technology*, December 1995, p. 35-39.

Metcalf & Eddy, Inc. *Wastewater Engineering: Treatment, Disposal and Reuse*. McGraw-Hill, Inc., New York, Third Edition, 1991.

Nemerow, N.L. and A. Dasgupta. *Industrial and Hazardous Waste Treatment*. Van Nostrand Reinhold, New York, 1991.

Pitter, P. and J. Chudoba. *Biodegradability of Organic Substances in the Aquatic Environment*. CRC Press, Boca Raton, Florida, 1990.

Richardson, M. *Nitrification Inhibition in the Treatment of Sewage*. The Royal Society of Chemistry, Burlington House, London, 1985.

U.S. Environmental Protection Agency. *Fine Pore Aeration Systems: Design Manual.* Center for Environmental Research Information, Cincinnati, EPA/625/1-89/023, 1989.

Water Pollution Control Federation. *Manual of Practice FD-8, Clarifier Design*. Lancaster Press, Lancaster, Pennsylvania, 1985.